(Bakun, 1990). Recent time series work in the central North Pacific (Karl, 1999) indicates that chlorophyll *a* concentrations and primary production in the surface waters there have more than doubled during the past three decades. The various studies using Secchi data can provide at least rough indications of longer-term variability and climatological trends in radiant heating rates. Finally, Ohlmann et al. (1998) have presented a regional/global analysis of mixed layer radiant heating and solar penetration. Input data included incident solar flux from the International Satellite Cloud Climatology Project and upper ocean chlorophyll concentration from CZCS. Some of the key results of the Ohlmann et al. (1998) analysis include: (1) solar penetration can be a significant fraction of the upper ocean mixed layer heat budget in the tropics and is important seasonally at mid- to high latitudes, and (2) annual climatological values of solar penetration can reach 40 W m^{-2}; omission would lead to overestimates of mixed layer heating of about 0.3°C $month^{-1}$.

5. Enabling Methodologies: Theories and Technologies

Theories and models, which can be used to estimate IOPs from AOPs and vice versa, are being developed, but further advances are still needed. The theoretical framework for biological modulation of radiant heating rates is quite well developed for conditions where the single-scattering approximation is valid. However, media where multiple scattering is very important, such as areas where coccolithophore blooms are occurring or have recently occurred, are considerably more challenging and more theoretical work will be required (Tyrell et al., 1999).

Considerable progress has been made in expanding the number of bio-optical observations, which can be made on virtually the same time and space scales as physical measurements such as temperature, salinity, and currents. This is due in large part to development of new in situ sensors, many of which are fairly small, require low power, and have high spectral resolution. It is anticipated that the trend in this direction will continue and that as more sensors and systems are sold commercially, the cost will decrease. Measurements of spectral absorption, scattering, and attenuation coefficients are advancing rapidly with improved spectral resolution capability (Moore et al., 1992; Bruce et al., 1996; Dana et al., 1998).

Higher spectral resolution measurements are now available for irradiance and radiance (M. Lewis, personal communication). Spectral fluorescence measurements, which can be used for identifying dissolved materials have been developed as well (e.g., Desiderio et al., 1997; Petrenko et al., 1998). Key optical measurements are now being developed for volume scattering and backscattering (Dana et al., 1998). These measurements are important for several optical studies, especially for remote sensing (which relies on a small backscattering signal and is affected by whitecapping and bubbles) and when scattering represents a large portion of the optical attenuation (e.g., the coccolithophore/coccolith problem). These latter measurements are also necessary for developing models, which can be used for estimating IOPs from AOPs and the inverse problem.

The interpretation of optical and bio-optical measurements remains an important problem in large part due to the complexity of the measured bulk properties. In some cases, in situ "groundtruthing" has proven valuable (e.g., comparisons of ^{14}C primary production measurements with mooring-based estimates), but in others the collection of water samples for comparison with in situ measurements has proven problematic.